

INFLUENCE OF TRANSIENT CONDITIONS ON OVERALL SERVICE  
LIFE OF TURBINE BLADES

G. N. Tret'yachenko

Translation of: "O Vliyaniy Neustanovivshikhsya Rezhimov  
na Obshchiy Resurs Raboty Turbinnykh Lopatok,"  
Problemy Prochnosti, Vol. 5, No. 3, March 1973, pp. 3-6.

(NASA-TT-F-15113) INFLUENCE OF TRANSIENT  
CONDITIONS ON OVERALL SERVICE LIFE OF  
TURBINE BLADES (Techtran Corp.) 8 p HC

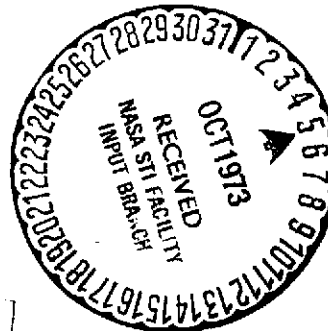
~~12.00~~

CSSL 21E

N73-31700

Unclass

G3/28 14202



Reproduced by  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
U.S. Department of Commerce  
Springfield, VA. 22151

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
WASHINGTON, D. C. 20546 SEPTEMBER 1973

8/10

## STANDARD TITLE PAGE

1. Report No. NASA TT F-15,113	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle INFLUENCE OF TRANSIENT CONDITIONS ON OVERALL SERVICE LIFE OF TURBINE BLADES		5. Report Date SEPTEMBER 1973	
		6. Performing Organization Code	
7. Author(s) G. N. Tret'yachenko		8. Performing Organization Report No.	
		10. Work Unit No.	
9. Performing Organization Name and Address Techtran Corporation P.O. Box 729 Glen Burnie, Maryland 21061		11. Contract or Grant No. NASw-2485	
		13. Type of Report and Period Covered  Translation	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes  Translation of: "O Vliyanii Neustanovivshikhsya Rezhimov na Obshchiy Resurs Raboty Turbinnykh Lopatok," Problemy Prochnosti, Vol. 5, No. 3, March 1973, pp. 3-6.			
16. Abstract  It is shown that, in spite of their relatively short duration, transient modes of operation of the type occurring during takeoff, landing, and engine tests have a tremendous effect on the service life of turbine blades. In view of this, it is suggested to carry out accelerated tests by determining the time to failure at steady modes of operation on the basis of data obtained with cylindrical samples, and at transient modes of operation, on the basis of tests performed with actual blades under simulated conditions.  <b>PRICES SUBJECT TO CHANGE</b>			
17. Key Words (Selected by Author(s))		18. Distribution Statement  Unclassified-Unlimited	
19. Security Classif. (of this report)  Unclassified	20. Security Classif. (of this page)  Unclassified	21. No. of Pages	22. Price

# INFLUENCE OF TRANSIENT CONDITIONS ON OVERALL SERVICE LIFE OF TURBINE BLADES

G. N. Tret'yachenko

A well-founded choice of blade testing modes which, on the one hand, would bring test conditions as close as possible to the actual and most characteristic operating conditions and, on the other hand, make it possible to generalize the results and forecast the durability of materials in other operating modes, is possible only on the basis of investigation of blades under conditions that reflect their actual load spectrum.

During the operation of each engine characteristic types of modes are observed, which may be encountered to a varying extent and in varying sequence, depending on conditions, throughout the entire service life of the engine. If, for example, the discussion concerns airplane engines, the most severe conditions under which maximum blade damage occurs are start-up, engine testing, takeoff and shutdown [1].

The overall turbine blade operating time until the appearance of cracks may be represented in the following form:

$$t_{\text{sum}}^* = \sum_0^t t_i, \quad (1)$$

where  $t_i$  is engine operating time in mode  $i$ .

The term  $t_i$  may vary significantly, depending on engine operating conditions, and this is reflected in blade service life  $t_{\text{sum}}^*$ . Let us examine how engine operating time in various modes, especially in transient ones, can influence this value. Subsequent evaluation is feasible if blade damage during operation under different conditions is known, for which purpose it is necessary first of all to analyze the endurance of the blades in the characteristic mode, and secondly to analyze their equivalence from the standpoint of the extent of influence on damage.

---

\*Numbers in the margin indicate pagination in the foreign text.

The failure time, assuming that the blades operate only in one mode  $i$ , is denoted through  $t_i^*$ . Here the relative damage in mode  $i$  during operation under various conditions will be

$$a_i = \frac{t_i}{t_i^*}.$$

As is customarily done when adding up the damage of specimens after fatigue or stress rupture strength tests with programmed change of load, we write

$$a_t = \sum_i a_i. \quad (2)$$

If the damage in the blade material builds up in proportion to the test time, then  $a_i = 1$ ; in the accelerated process  $a_i \ll 1$  and in the decelerated process  $a_i > 1$ .

It is known from the literature [2, 3] that during stress rupture strength or creep tests of cylindrical specimens cyclic loads and heating facilitate damage processes, which exclude the possibility of simple linear summation of the damage without introducing some error. The value  $a$  (analog of  $a_i$ ) is 0.3 to 0.4. This gives reason to assume that in blades also damage builds up faster when they are added in the various modes of operation. In the case at hand, however, there is some difference, which consists in the following. First, summation is done not in terms of the individual states of the material during repeated changes in a given mode, but rather for repetition of the modes as a whole, with complex internal laws; in other words we add up the damage caused by the cyclic actions of "blocks" of power and the temperature loads. Secondly, since the blades operate in the complex stress and nonuniform thermal state, changing rapidly in time, the criterion of damage accumulation and failure is taken arbitrarily, in which connection the rate of appearance and change of these criteria may vary substantially. Thus, for example, if the appearance of a crack of conventional length is taken as the criterion of failure, then, in connection with the fact that reduction of the stress level often facilitates the growth of thermal cracks, with the result that their spreading is unlimited,  $a_t$  may change appreciably, depending on the choice of failure criteria. Thus we arrive at the conclusion that during analysis of blade damage under conditions of heat exchange, simulating operation under actual conditions, the hypothesis

of linear summation requires considerable refinement. But since such data are not yet available, we will assume that  $a_i \approx 1$ .

Expression (1) is written in the following form:

$$t_{\text{sum}}^* = \sum_i^t a_i t_i^*,$$

We assume here that condition (2) is valid. We assume further that

$$t_i^* = k_i t_j^*,$$

where  $k_i$  is the mode equivalence coefficient;  $t_j^*$  is the time to failure in one characteristic mode.

The failure time of blades during operation in different modes is

$$t_{\text{sum}}^* = t_j^* \sum_i^i a_i k_i. \quad (3)$$

Any mode may be used as the characteristic mode  $j$ . For example, we will use the mode in which the engine operates for maximum time  $t_{\text{st}_1}^*$ . We write the following expression:

$$t_{\text{sum}}^* = t_{\text{st}_1}^* (a_{\text{st}_1} + k_{\text{st}_2} a_{\text{st}_2} + \dots \text{ and } k_{\text{tr}_1} a_{\text{tr}_1} + k_{\text{tr}_2} a_{\text{tr}_2} + \dots).$$

Introducing the definitions

$$a_{\text{st}}^k = a_{\text{st}_2} + k_{\text{st}_2} a_{\text{st}_2} + \dots) \quad a_{\text{tr}}^k = k_{\text{tr}_1} a_{\text{tr}_1} + k_{\text{tr}_2} a_{\text{tr}_2} + \dots$$

we obtain

$$t_{\text{sum}}^* = t_{\text{st}_1}^* (a_{\text{st}}^k + a_{\text{tr}_1}^k) = t_{\text{st}_1}^* k_{\text{st}} (a_{\text{st}} + a_{\text{tr}} \frac{k_{\text{tr}}}{k_{\text{st}}});$$

$$a_{\text{st}} + a_{\text{tr}} = 1.$$

Since blade damage occurs considerably faster in transient modes than in steady state ones, the ratio  $\frac{k_{\text{tr}}}{k_{\text{st}}}$  will be of small value — hundredths or tenths of unity. It follows in this connection that a short time of operation in transient modes (an increase in  $a_{\text{tr}}$ ) results in substantial reduction of the overall service life  $t_{\text{sum}}^*$  of the blades.

Such transient modes as startup, startup-shutdown-testing and the like influence service life variously. In order to evaluate the overall service life, as follows from the material presented above, it is necessary to know the mode equivalence coefficients  $k_1$ . Experimental investigations of the service life of the blades of the first stage of one aircraft engine were conducted for this purpose in [4]. The blades were made of alloy ZhS6-K.

The conditions of the three characteristic operating modes, namely startup-testing-shutdown, startup-shutdown and startup-takeoff, were simulated [4]. The experimental setup made it possible to conduct investigations with automatic holding of the programs.. The action of centrifugal forces that occur during operation of turbine blades was not simulated in these tests. The appearance of a crack 0.5 mm long was used as the failure criterion. /5

It was established as a result of the experiments that the most unfavorable operating mode is the one corresponding to the startup-shutdown of the engine. During tests in this mode cracks appeared after an average of 300 cycles. In the startup-testing-shutdown mode the number of cycles before failure was 612, and 725 in the startup-takeoff-shutdown mode.

The blade operating time to failure in these modes, considering that the duration of the modes were 3, 11 and 8 minutes, respectively, was  $t_{s.t}^* = 15$  hours,  $t_{s.t.sh}^* = 112$  hours,  $t_{s.to.sh}^* = 97$  hours.

Since it was not possible in the given work to determine the value  $t_{st}^*$ , we will analyze only the equivalence of the investigated transient modes in relation to the startup-test-shutdown mode. These coefficients will be  $k'_{s.t} = 0.13$ ;  $k'_{s.to.sh} = 0.86$ ;  $k'_{s.t.sh} = 1$ .

If tests are conducted to failure during alternation of the stated 3 modes, and if we use the linear hypothesis of summation of damage, we may write

$$t'^* = t_{s.t.sh}^* (a'_{s.t.sh} + a'_{s.to.sh} k'_{s.to.sh} + a'_{s.t} k'_{s.t}):$$

$$a'_{s.t.sh} + a'_{s.to.sh} + a'_{s.t} = 1.$$

In the given investigated case

$$t'^* = 112(a'_{s.t.sh} + 0.86a'_{s.to.sh} + 0.13a'_{s.t}).$$

The experimental expression derived for  $t^*$  confirms and explains the laws observed during actual engine operation. A slight increase in the operating time (number of cycles) in the startup-shutdown mode leads to a substantial reduction of blade service life  $t^*$  in transient modes.

We will assume that the blades are so designed that the failure time in steady state modes  $t_{st}^{*''} = 2000$  hours, and in the failure time in the transient modes  $t_{tr}^{*''} = 200$  hours. Then

$$t_{sum}^{*''} = t_{st}^{*''} (a_{st}^{*''} + k_{tr}^{*''} a_{tr}^{*''}) = 2000(a_{st}^{*''} + 0.1a_{tr}^{*''}).$$

It follows from this example that the exhaustion of 10% of the service life of the transient modes corresponds to 90% exhaustion of the overall service life of the blades; 20% exhaustion of the service life of the transient modes corresponds to 18% exhaustion of overall service life, etc. As we see, the difference is small. This means that the transient modes play the most important part in blade damage and have the greatest effects on their service life.

Damageability and service life of turbine blades are best judged in terms of these modes. The relations examined above may also be used in the development of accelerated test methods. In order to develop these methods, obviously, it will be necessary to undertake a detailed analysis of failure time and equivalence coefficients of the transient mode, which comprise an insignificant fraction of the overall service life of turbine blades. The failure time of blades operating in steady state modes, which is one or even two orders of magnitude greater, obviously should not always be investigated during gas dynamic stand tests for the following reasons: first, it is not economical, and second, in the steady state modes, when a thermal and stress states of the blades are most uniform and comparatively low, it makes sense to calculate the service life of the blades in terms of the fatigue and endurance characteristics of the material, determined in tests of standard cylindrical specimens. The characteristics determined by accelerated methods of determining fatigue and stress rupture strength may be used.

### Conclusions

1. The overall service life of turbine blades depend to a large extent on engine operating conditions.

2. The influence of the various transient modes, which comprise comparatively small fractions of the overall service life, on blade service life is so great that specifically the transient modes determine overall service life.

3. The determination of the mode equivalence coefficients and failure time in each operating mode, particularly transient modes, makes it possible to predict turbine blade service life under actual operating conditions;

4. Accelerated tests may be conducted as follows: the failure time in steady state modes is determined on the basis of tests of cylindrical specimens; in transient modes it is determined in tests of real blades under conditions that simulate actual operating modes. /6

#### REFERENCES

1. Khalimoi, F. F., V. I. Kuriat et al., "Influence of Operating Factors on Aviation Gas Turbine Blade Performance," in the book: *Termoprochnost' Materialov i Kunstruktivnykh Elementov* [Thermal Strength of Materials and Thermal Parts], 4th Edition, Naukova Dumka, Kiev, 1967.
2. Sizova, R. N., "Some Principles of Nonstationary Creep and Their Influence On Stress State," in the book: *Termoprochnost' Materialov i Kunstruktivnykh Elementov* [Thermal Strength of Materials and Thermal Parts], 5th Edition, Naukova Dumka, Kiev, 1969.
3. Serensen, S. V., "The Criteria of the Strength of Materials for Transient Loading at High Temperatures," in the book: *Termoprochnost' Materialov i Kunstruktivnykh Elementov* [Thermal Strength of Materials and Thermal Parts], 4th Edition, Naukova Dumka, Kiev, 1967.
4. Kravchuk, L. V., R. I. Kuriat and F. F. Khalimoi, "Methods of Analyzing Thermal Fatigue of Gas Turbine Blades During Programmed Thermal Loading," in the book: *Termoprochnost' Materialov i Kunstruktivnykh Elementov* [Thermal Strength of Materials and Thermal Parts], 4th Edition, Naukova Dumka, Kiev, 1967.

Translated for the National Aeronautics and Space Administration under Contract No. NASw-2485, by Techtran Corporation, P.O. Box 729, Glen Burnie, Maryland, 21061; translator: Orville E. Humphrey.